MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2019/2020

ENT3076 – NANO-SCIENCE

(NANO)

28 FEBRUARY 2020
9:00 a.m – 11.00 a.m
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 6 pages with 4 Questions only.
2. Attempt **ALL** questions. All questions carry equal marks and the distribution of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.

List of Constants

Electron mass in free space, $m_o = 9.11\times 10^{-31}$ kg
One electron volt, (1eV) = 1.60×10^{-19} J
Electronic charge, $e = 1.60 \times 10^{-19}$ C
Planck's constant, $h = 6.63 \times 10^{-34}$ Js
Reduced Planck's constant, $\hbar = 1.05 \times 10^{-34}$ Js
Boltzmann constant, $k_B = 1.38 \times 10^{-23}$ JK^{-1}
Temperature in Kelvin, T(K) = T(°C) + 273 K
Permittivity of free space, $\varepsilon_o = 8.85 \times 10^{-14}$ Fcm^{-1}

List of Formulas

$$n = 1 + \sqrt{\frac{2m^* V_b L^2}{\pi^2 \hbar^2}}$$

$$\varepsilon_{n1,n2} = \frac{\hbar^2 \pi^2}{2m^*}\left(\frac{n_1^2}{L_x^2} + \frac{n_2^2}{L_y^2}\right)$$

$$\varepsilon_1 \approx \frac{m^* V_b^2 L^2}{2\hbar^2}$$

$$\frac{\rho}{L} = \frac{1}{\pi}\sqrt{\frac{2m^*}{\hbar^2}} \sum_{n1,n2} \frac{1}{\sqrt{E - \varepsilon_{n1,n2}}} \Theta\left(E - \varepsilon_{n1,n2}\right)$$

$$\frac{\rho}{S} = \frac{m^*}{\pi\hbar^2} \sum \Theta\left(E - \varepsilon_n\right)$$

$$N_t = \frac{2\sqrt{2}m^{*\frac{3}{2}}}{3\pi^2\hbar^3} |V_b|^{\frac{3}{2}} L_x L_y L_z$$

$$j = e\left(\mu_B n_B d_B + \mu_W n_W d_W\right)\frac{F}{d}$$

$$v_z = \sqrt{\frac{2\varepsilon}{m^*}}$$

$$\Gamma = \left(T_l + T_r\right)\frac{v_z}{2L_w}$$

$$\Gamma = T\frac{v_z}{2L_w}$$

Continued ...

Question 1

Table Q1 listed the basic parameters of GaAs and AlN. A quantum wire as shown in Figure Q1 is fabricated using these materials.

Table Q1

Material	Electron Affinity	Energy Bandgap	Electron Effective Mass	Hole Effective Mass
GaAs	4.07 eV	1.42 eV	$0.063m_o$	$0.51m_o$
AlN	0.60 eV	6.03 eV	$0.40m_o$	$7.20m_o$

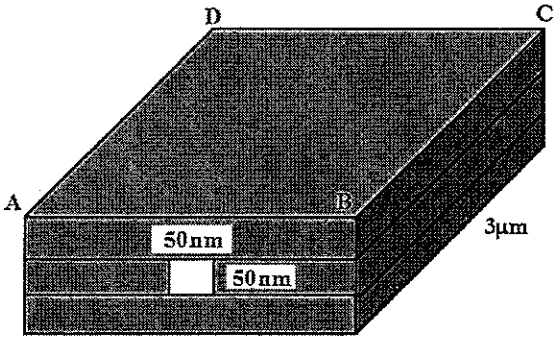

Figure Q1

(a) Calculate energy subbands of holes confinement, $\varepsilon_{(n1,n2)}$ at $(n1,n2)$ = (1,1), (1,2), (1,3), (2,2), (2,3) and (3,3). [8 marks]

(b) Predict the energy subbands of holes confinement, $\varepsilon_{(n1,n2)}$ at $(n1,n2)$ = (2,1), (3,1), and (3,2). Justify your answer. [5 marks]

(c) Calculate the density of states per unit length for holes if the total energy of holes gas in the quantum wire is 2.5 meV. [4 marks]

(d) Sketch the density of states for one dimensional holes in this quantum wire and clearly label $\varepsilon_{(n1,n2)}$ in your diagram. [6 marks]

(e) Give a suggestion on how to transform this quantum wire structure into quantum dot structure. [2 marks]

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Question 2

(a) Figure Q2 shows the energy band structure of a semiconductor material.

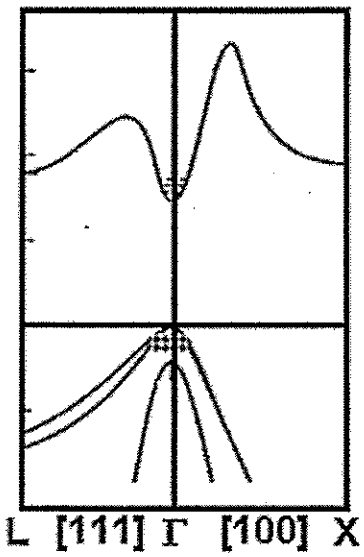

Figure Q2

(i) Suggest a semiconductor material for this energy band structure and justify your answer. [3 marks]

(ii) Under the concept of free electron mass, justify the differences on the behavior of electrons fall in valley at Γ and X. [6 marks]

(iii) With the aid of diagrams, explain the formation of light holes and heavy holes in valence band. [8 marks]

(b) Table Q2 listed the electron affinity and energy bandgap for material A, B and C.

Table Q2

Material	Electron Affinity	Energy Bandgap
A	3.5 eV	1.0 eV
B	5.0 eV	0.9 eV
C	2.8 eV	2.4 eV

(i) Give the combination of materials that will form straddling quantum well structure. Sketch the structure and label electron affinity, energy bandgap and materials in the diagram. Comment the carrier confinement in this structure. [4 marks]

(ii) Give the combination of materials that will form staggered quantum well structure. Sketch the structure and label electron affinity, energy bandgap and materials in the diagram. Comment the carrier confinement in this structure. [4 marks]

Continued ...

Question 3

(a) Figure Q3 shows the transient response of electron drift velocity to steplike pulses of the electric field at room temperature for silicon (Si) and GaAs.

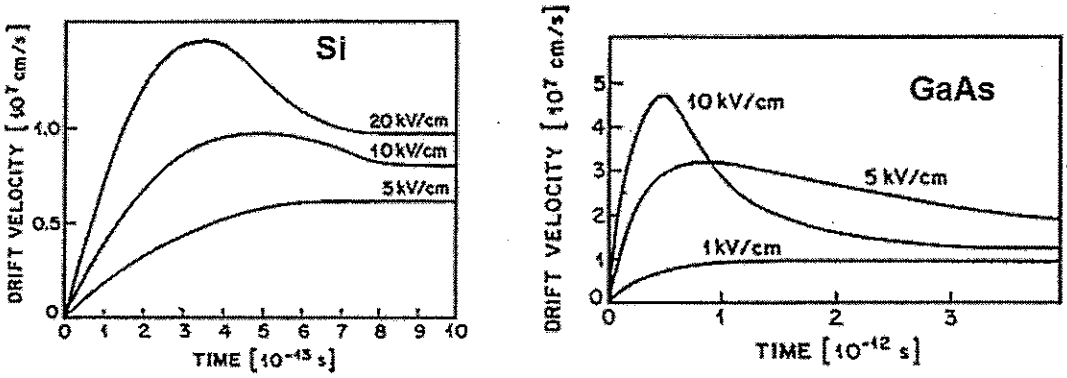

Figure Q3

(i) With the aid of a diagram, explain why GaAs has different transient response of electron drift velocity compare to Si. [8 marks]

(ii) If the dimensions of GaAs are decreased until a GaAs quantum wire is formed, explain how electron drift velocity responses to applied electric field. [9 marks]

(b) Material D has electron affinity at 2.0 eV and the next upper minima valley at 1.4 eV. Given that electron affinity of material E, F and G are 0.9 eV, 2.5 eV and 1.7 eV, respectively.

(i) Which material is suitable to be used as barrier in ballistics-injection devices that fabricated by material D? Justify your choice. [6 marks]

(ii) Calculate the velocity of electrons in the base region of ballistics-injection devices if the electron effective mass of material D is $0.08m_o$. [2 marks]

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Question 4

(a) Figure Q4 shows the current-voltage characteristic of an InGaP/GaAs resonant-tunneling bipolar transistor. With the aid of diagrams, explain how the transistor operates to gain the current-voltage characteristic. [9 marks]

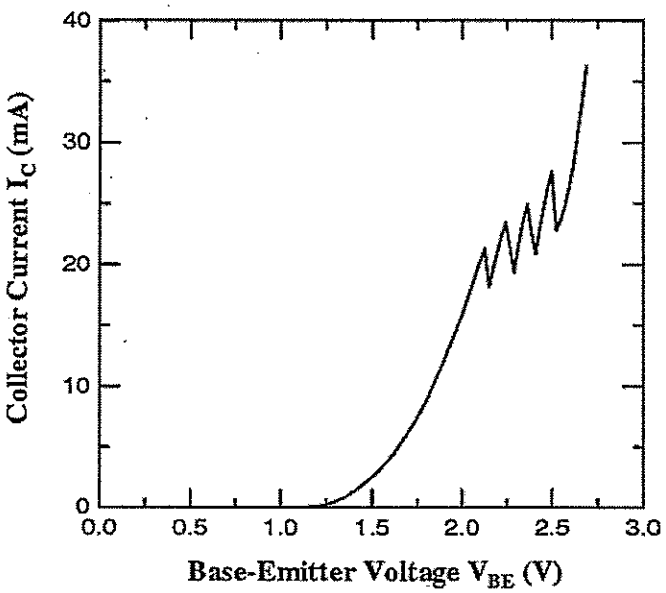

Figure Q4

(b) A quantum well structure is used to fabricate a solar cell. Wavelength <1036 nm and <863 nm can respectively excite electrons from first and second subband in valence band to conduction band. Given that energy bandgap for active layer is 1.12 eV.

(i) Which energy subband in conduction band will the electrons be excited to by the wavelength <86 3nm? Justify your answer. [4 marks]

(ii) If $\varepsilon_{c,1} = \varepsilon_{v,1} + 0.02$ eV, calculate the first energy subband in conduction band and valence band. [6 marks]

(iii) Sketch the energy band of quantum well with the indication of the allowed and forbidden interband phototransition. [6 marks]

End of Paper.